Transportation Research Part B 72 (2015) 40–58

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

Optimal transit routing with partial online information

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ARTICLE INFO

Article history:
Received 19 December 2013
Received in revised form 11 November 2014
Accepted 12 November 2014
Available online 5 December 2014

Keywords:
Routing
Hyperpath
Partial information
Attractive set
Cycles

ABSTRACT

This paper studies the routing strategy in a transit network with partial online information at stops. By partial online information, we mean that the arrival time of the incoming transit vehicles is available for a subset of the lines serving a stop. To cope with the partial information assumption, a new routing strategy is proposed and closed form formulae for computing expected waiting times and line boarding probabilities are derived. The proposed strategy unifies existing hyperpath-based transit route choice models that assume either no information or full information. Like many existing models, it ensures optimality when all information is available or the headway is exponentially distributed. The problem of determining the attractive set is discussed for each of the three information cases. In particular, a new heuristic algorithm is developed to generate the attractive set in the partial information case, which will always yield a solution no worse than that obtained without any information. The paper also reveals that, when information is available, an optimal hyperpath may contain cycles. Accordingly, the cause of such cycles is analyzed, and a sufficient condition that excludes cycles from optimal hyperpaths is proposed. Finally, numerical experiments are conducted to illustrate the impact of information availability on expected travel times and transit line load distributions. Among other findings, the results suggest that it is more useful to have information on faster lines than on slower lines.

1. Introduction

In a transit network where multiple lines share several stops and segments of routes, passengers often face the choice of transit lines when they arrive at a stop. Chriqui and Robillard (1975) first studied this "*common bus lines*" problem using a simple corridor example. In this seminal work, Chriqui and Robillard (1975) show that passengers may select a set of attractive lines to minimize the expected total travel time. The corresponding route choice strategy is boarding the first arriving line in that *attractive set*. Spiess and Florian (1989) extended this notion of strategy to a general transit network, namely, the choice of an attractive set of lines is considered at each node where boarding occurs. Nguyen and Pallottino (1988) interpreted a strategy as a *hyperpath*, which is defined as an acyclic directed graph connecting an origin to a destination. Methods for finding optimal hyperpaths have been proposed and incorporated into various frequency-based transit assignment models (see e.g. Spiess and Florian, 1989; Nguyen and Pallottino, 1988; de Cea and Fernández, 1993; Wu et al., 1994; Marcotte et al., 1998; Cominetti and Correa, 2001; Kurauchi et al., 2003; Hamdouch et al., 2004; Cepeda et al., 2006; Schmöcker et al., 2008; Trozzi et al., 2013). The notion of hyperpath has also been used in building reliable routing models for highway networks (see e.g., Bell, 2009; Bell et al., 2012; Schmöcker et al., 2009; Ma et al., 2013).

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http://dx.doi.org/10.1016/j.trb.2014.11.007
0191-2615/

The classical hyperpath model relies on several assumptions. First, transit line headway is typically assumed to be exponentially distributed. Recent studies (Li et al., 2015; Ruan and Lin, 2009), however, suggest that empirical headway data fit other types of distributions (such as Gamma and Erlang) much better than the exponential distribution. Second, passengers are assumed to arrive at stops randomly, which approximates the reality well when headway does not exceed certain threshold (around 10–13 min) (O'FLAHERTY and Mancan, 1970; Okrent, 1974; Seddon and Day, 1974; Bowman and Turnquist, 1981; Fan and Machemehl, 2009). Third, passengers are also assumed to have no access to on-line information (i.e., the knowledge of the arrival times of incoming transit vehicles). Yet, such information is readily available nowadays via display boards at stops or transit apps on mobile devices (see e.g., BusTracker offered by Chicago Transit Authority[1]). As the availability of such online information may affect the boarding decision significantly, it is important to incorporate it into transit route choice models.

The role of real-time information in the common bus lines problem was studied in Hickman and Wilson (1995), which assumed that waiting time distributions vary as passengers gather more information after arriving at a stop. Accordingly, passengers would only board the transit vehicle if the expected travel time upon boarding is smaller than the minimum expected travel time if the vehicle is skipped. Because each boarding decision invokes an evaluation of the expected travel time, computing boarding probabilities is not analytically tractable. Instead, simulations are used to evaluate the value of information in a rather small case study. Gentile et al. (2005) assumed that the arrival time of next transit vehicle can be accurately projected once passengers arrive at a stop. Thus, passengers will always board the transit vehicle that has the minimum total travel time.

This study is focused on the impact of information availability on transit route choices. Specifically, we consider a situation in which passengers can only access online waiting time information for a subset of the available lines at a stop. In contrast, Gentile et al. (2005) assumed that such information is available for all lines. The ability to cope with partial information is important because limitations in the current vehicle location technology and random incidents could render incomplete information in the transit system. The partial information case may also be regarded as a generalization of two special cases: no information and full information. As it turns out, the availability of partial information leads to very different route choice strategies that pose greater analytical and numerical challenges for computing expected waiting time and boarding probabilities. Tackling these challenges is a focus of this paper.

The rest of the paper is organized as follows. The existing stop model of route choice in transit networks is reviewed in Section 2. Section 3 proposes the route choice strategy in the partial information case. Closed-form formulae for computing boarding probabilities and expected waiting times are presented for the exponential headway distribution in Section 4. Section 5 discusses the attractive set problem in all three information cases, and Section 6 addresses the cycle issue in optimal hyperpaths when information is available. Results of numerical experiments are reported in Section 7. Section 8 concludes the paper.

2. Stop model

Consider a stop in a transit network that is shared by multiple transit lines $L = \{1, 2, \ldots, n\}$. For each line $i \in L$, let s_i denote the line travel time and h_i denote the headway of the line i. The basic assumptions of the stop model, widely adopted in the literature to simplify the analysis (e.g. Spiess and Florian, 1989; Gentile et al., 2005), are as follows:

Assumption 1.
Transit line headways are statistically independent with given continuous distributions.

Assumption 2.
Passengers arrive randomly at the stop, i.e., they do not coordinate their arrival times at the stop with the scheduled arrival times of transit vehicles.

Assumption 3.
Transit line travel time is deterministic.

Assumption 4.
Passengers can reliably estimate the remaining line travel time, i.e., the expected travel time from the stop to the destination, once boarded a vehicle of the line.

Assumption 5.
Passengers are always able to board the next coming transit vehicles, i.e., congestion effects are not considered.

[1] http://www.ctabustracker.com/bustime/home.jsp